GPS/GLONASS TIME TRANSFER WITH 20-CHANNEL DUAL GNSS RECEIVER

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Abstract

One of the world's two global satellite navigation systems, GPS, is already fully operational (April 1994) and the other, GLONASS, will become operational by the end of 1995 or early 1996. Each will offer, independently of the other, precise location and time transfer continuously anywhere in the world and indeed in space itself. Many potential users, in particular the civil aviation community, are keenly interested in a joint GPS/GLONASS operation since it would offer substantial advantages in defining and maintaining the integrity of the navigation aid. Results are presented on the characterisation of GPS/GLONASS time comparison using a 20-channel dual receiver developed & constructed at the University of Leeds, UK.

INTRODUCTION

GLONASS provides worldwide time dissemination and time transfer services in the same manner as Navstar GPS with both exhibiting substantial advantages over other existing timing services. Time transfer is both efficient and economic in the sense that direct clock comparisons can be achieved via GLONASS between widely separated sites without the use of portable clocks. Event time tagging can be achieved with the minimum of effort and users can reacquire GLONASS time at any instant due to the continuous nature of time aboard the satellites.

The first release from the Soviet Union of detailed GLONASS information occurred at the International Civil Aviation Organisation (ICAO) special committee meeting on Future Air Navigation Systems (FANS) in Montreal in May 1988. In full operation GLONASS, like GPS, will have 24 satellites in orbit, 8 satellites separated by 45 degrees in phase in each of three planes 120 degrees apart. Currently 22 GLONASS satellites are in full operation, 8 each in planes 1 and 3 and 6 in plane 2. In the event of no failures before the next triple launch planned for early December 1995, a full constellation will be available around the end of 1995.

TIME FROM GPS/GLONASS

Time transfer from GPS/GLONASS is achieved in a straightforward manner. Each satellite transmits signals referenced to its own on-board clock. The Control Segment monitors the

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satellite clocks and determines their offsets from the common GPS/GLONASS system time. The clock offsets are then uploaded to satellites as part of their transmitted data message. A user at a known location receives signals from a satellite and by decoding the data stream modulated on to the transmission, is able to obtain the position of the satellite, as well as the satellite's clock offset from the common system time. Hence the signal propagation time can be calculated at any instant. The time at which the signals are transmitted is also contained in the data message; by combining this with the propagation time and correcting first for atmospheric effects and other delays and then for the satellite's own clock offset, the user can effect transfer to GPS/GLONASS system time. Correction to an external time scale (such as UTC(USNO) or UTC(SU)) is then possible since the relevant offset is one of the transmitted data parameters. Any other user who has the same satellite visible is also able to transfer to the same common time scale.

SATELLITE CLOCK OFFSETS

GLONASS clock offsets [1] are transmitted as part of each satellite's ephemeris data once every half–hour. The clock information arrives in the form of two parameters (i) the SV clock phase offset from GLONASS system time, a_0 and (ii) the SV clock fractional frequency offsets from the GLONASS system reference, a_1. The clock offset a_2, the second rate of change of phase used in GPS, is not employed by GLONASS as the half–hour update makes this unnecessary. GLONASS does transmit one additional timing parameter – the phase offset between system time and its reference standard, A_0. This last offset is normally only updated once a day. There is again a parallel here between the two satellite navigation systems as GPS also transmits a phase offset between GPS system time and its reference standard, UTC(USNO).

GPS/GLONASS TIME TRANSFER MEASUREMENTS

A series of tests[2] was conducted during November 1994 between UTC(LDS) and UTC(NPL) in the UK using dual, multi–channel GNSS receivers developed in the University of Leeds capable of simultaneous GPS and GLONASS code–phase time transfer. Position coordinates at the Leeds venue are known to better than 2 m while the National Physical Laboratory, UK (NPL) are certainly much better. The object of this test was to establish the degree to which time could be transferred between the two UTC references using first GPS and then GLONASS. Each receiver was synchronised to the local UTC reference and set to run for 24 hours continuously.

In the first instance the UTC reference was compared to satellite system time with each receiver operating independently in a non–differential mode. In this way the measurement made over a satellite pass of several hours duration would show up the totality of the systematic & random errors to which this kind of test is naturally subject. In the case of GPS the outstanding error source is "selective availability" (SA) as can readily be observed in Figure 1. The effect is displayed dramatically in this Figure – measured pseudo–range from PRN 4 corrected to refer to system time. In comparison results for the same test (see Figure 2) relating to GLONASS over an equally long satellite pass on the same day using GLONASS 1 (almanac slot 1) show

no SA effect, dispersion due to random noise and a clear linear slope deriving from the (small) frequency differences between the clocks involved. The increased level of noise at the beginning and end of the test results from effects experienced at very low satellite elevation.

Subtraction of the data sets taken at Leeds and NPL eliminates the common system time reference and most of the systematic errors in the measurement, including SA, satellite orbit & clock errors, local position and clock errors and the ionosphere. The results relating UTC(LDS) to UTC(NPL) are shown in Figure 3 (GPS) and Figure 4 (GLONASS) agreeing to about 1.5 ns with spreads of 4.4 and 7.0 ns respectively. Clearly there are other data sets whose mean values do not agree so closely as the set chosen.

RELATIVITY CORRECTIONS in GLONASS

In an excellent discussion[3] on the effect of relativity corrections on GPS satellite signals, it is shown how both general and special relativity corrections are transmitted in the GPS data message so as to allow the user to correct ranging measurements. Due to the high stability of GNSS satellite on–board clocks, the relativistic variations are, in fact, larger than the effects of clock stability itself. Because of the effect of special relativity alone, clock oscillators have to be offset on the ground before launch, in the case of GPS, by -4.45×10^{-10} in frequency. Including the effects of both special and general relativity, the time–varying component of relativity is shown to be as large as 45.8 ns for a GPS orbit with maximum eccentricity, e= 0.02 (this orbital parameter expresses the non-circularity of the orbit).

It is a fact that GLONASS satellites have orbits which are normally more circular than GPS satellites. This means that the general relativity correction which depends on the distance of the satellite from the centre of the earth is smaller for GLONASS satellites than for GPS satellites simply because the distance variation is less. The combined relativistic effects are shown[3] to produce a variation in the satellite frequency with peak–to–peak fractional frequency linearly dependent on eccentricity (e small). The variation is cyclic with period the same as the orbital period with the minimum value occurring at time of perigee . The GLONASS satellite with the largest eccentricity was GLONASS 47 (channel 4) with e = 0.0060. The next largest eccentricity is e = 0.0038 for GLONASS 48 (channel 13) – all other GLONASS satellites have e less than 0.0025. Calculation shows that the fractional frequency peak–to–peak change over an orbit amounts to 4.2 ps/s for GLONASS 47 and 2.6 ps/s for GLONASS 48. For all other satellites the magnitude of the effect is of the order of the clock frequency data resolution (0.9 ps/s) and is difficult to observe. The only satellite currently in action which exhibits the effect is GLONASS 76 (e = 0.0037).

Since no relativistic corrections are transmitted by GLONASS in the data message, yet the corrections must be implicit in the ranging scheme, the question arises – how are the relativity terms included? We have found that the corrections are included directly in the phase and frequency offsets transmitted by GLONASS satellites. By logging GLONASS ephemerides (updated every half–hour) over a satellite pass with high elevation, it is possible to obtain values of clock phase and frequency offset over more than 5 hours, slightly less than half the orbital period. Should the observation interval coincide with the time which encompasses a minimum and maximum of the phase and frequency changes, it is possible to extract the peak–to–peak

values for an orbit. It is observed that the peak–to–peak values of a cyclic fractional frequency in GLONASS 47 are 4.5 ps/s (cf 4.2 ps/s) and for GLONASS 48 are 2.7 ps/s (cf 2.6 ps/s). It is also confirmed from satellite data that the minimum value of the relativistic fractional frequency correction occurs at the time of perigee. The cyclic effect is also clearly observed in residuals of the clock phase data transmitted by these satellites. It is concluded that relativistic corrections to GLONASS orbits are transmitted as phase and frequency corrections within the GLONASS data message and require no intervention on the part of the user.

When analysing GLONASS satellite clock data for the purpose of establishing estimates of clock stability, it is important to remove the effects of relativistic effects first; otherwise these corrections are interpreted as satellite clock instability.

FREQUENCY RE–USE & BAND RELOCATION

Frequency re–use would involve antipodal satellites in the GLONASS system using the same transmit frequency. In this way satellites on opposite sides of the earth would not interfere with each other, allowing the entire space segment to be implemented with only 12 channels. One exception to this rule would be high–flying receivers on-board satellites attempting to use GLONASS for navigation purposes. However even in cases such as these, modern receiver techniques are sophisticated enough to distinguish between the two mutually–interfering signals. Currently (November 1995) 18 of the 22 operational satellites have a paired frequency allocation. The removal of the top 12 channels of GLONASS would reduce the required bandwidth by 6.75 MHz, saving spectrum where it is most needed – at the top of the band.

A second solution to the problems raised above would be to relocate the entire frequency band occupied by GLONASS down towards the GPS band. Between the lower edge of the current GLONASS band and upper end of the GPS band, there is already room for a shift of almost 12 MHz. With the anti–interference properties enjoyed by both GPS and GLONASS (spread–spectrum processing gain), there is room possibly for an even larger shift. The relocation solution has the potential to resolve all of the interference difficulties being met. This course of action as well as frequency re–use is currently under consideration by the GLONASS administration. Relocation of the frequency band would clearly have a large impact on receiver implementation, resulting in a major upheaval amongst current users of the system.

A "half-way" solution has also been suggested whereby GLONASS would use both frequency re–use and re–location by halving the number of channels used not by removing the top 12 channels but rather by removing the top 18 channels and adding 6 channels at the lower end of the spectrum. In this way, the "old" channel 1 at 1602.5625 MHz would become the "new" channel 7. The "new" spectrum would then extend from 1594 - 1610.5 MHz.

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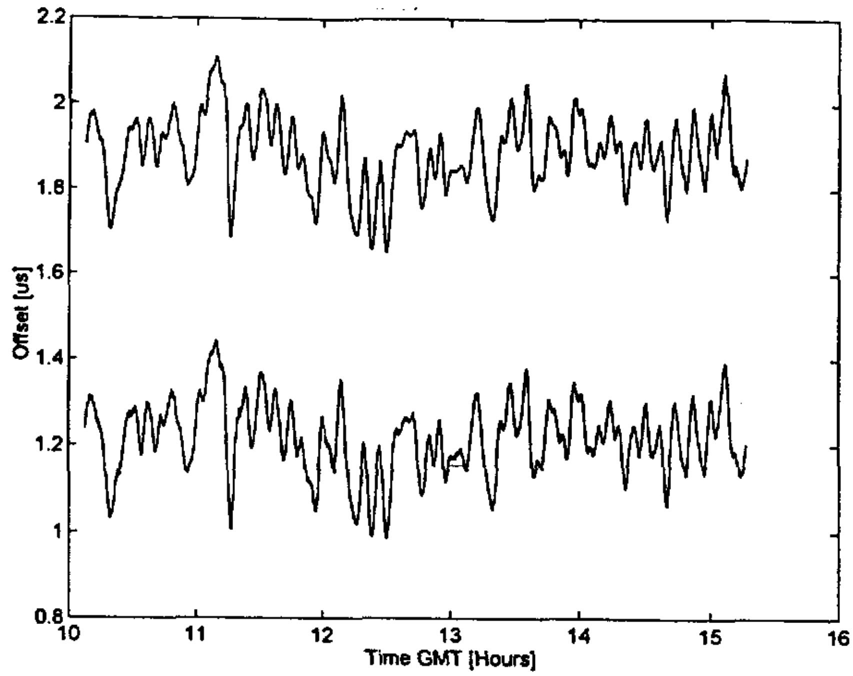

Figure 1: **UTC(LDS) & UTC(NPL2) - GPS system time PRN 4 → 4 Nov '94**

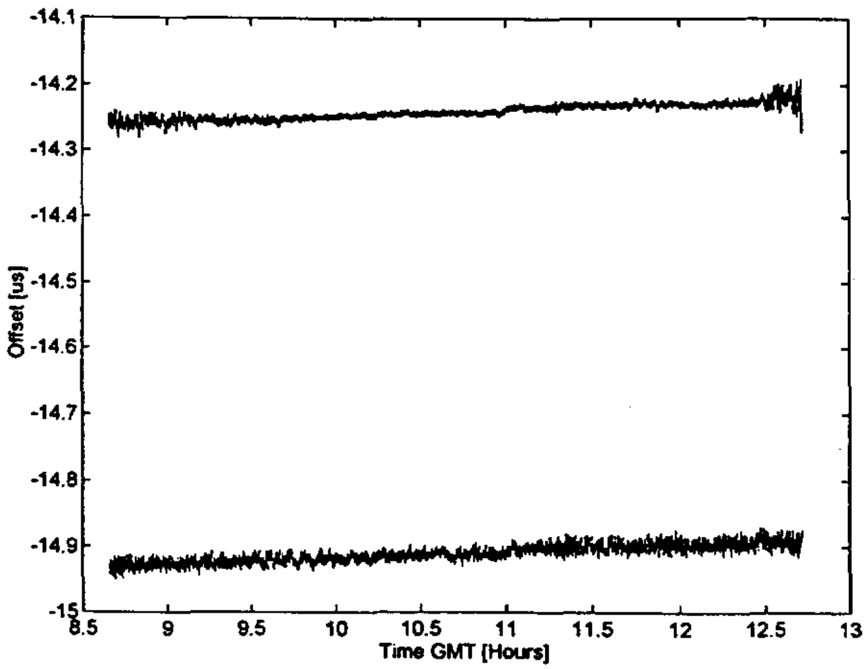

Figure 2: **UTC(LDS) & UTC(NPL2) - GLONASS system time GLONASS 1 → 4 Nov '94**

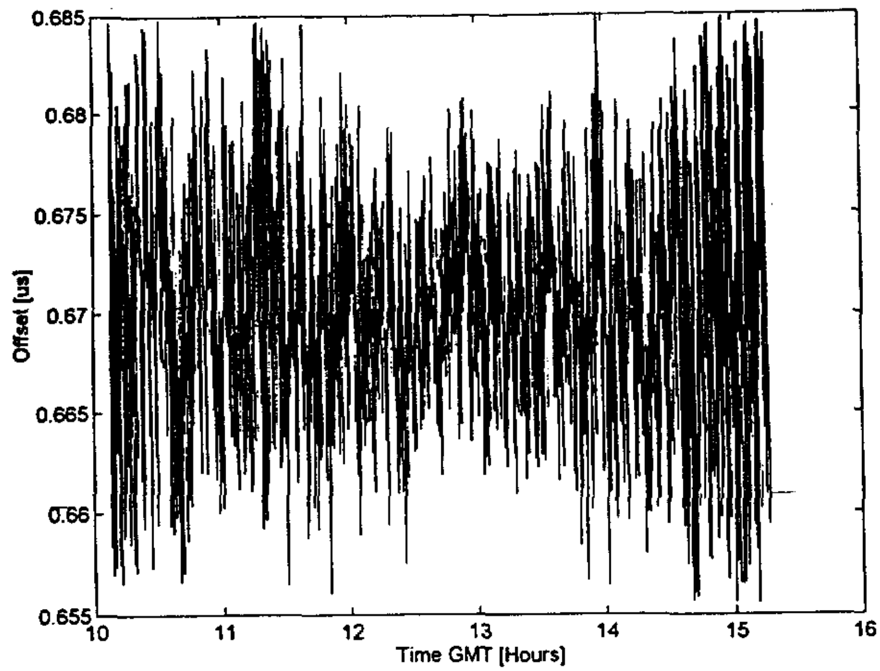

Figure 3: **UTC(LDS) - UTC(NPL2) → PRN 4 on 4 Nov '94**
mean value = 670.3 ns; 1-σ = 4.4 ns

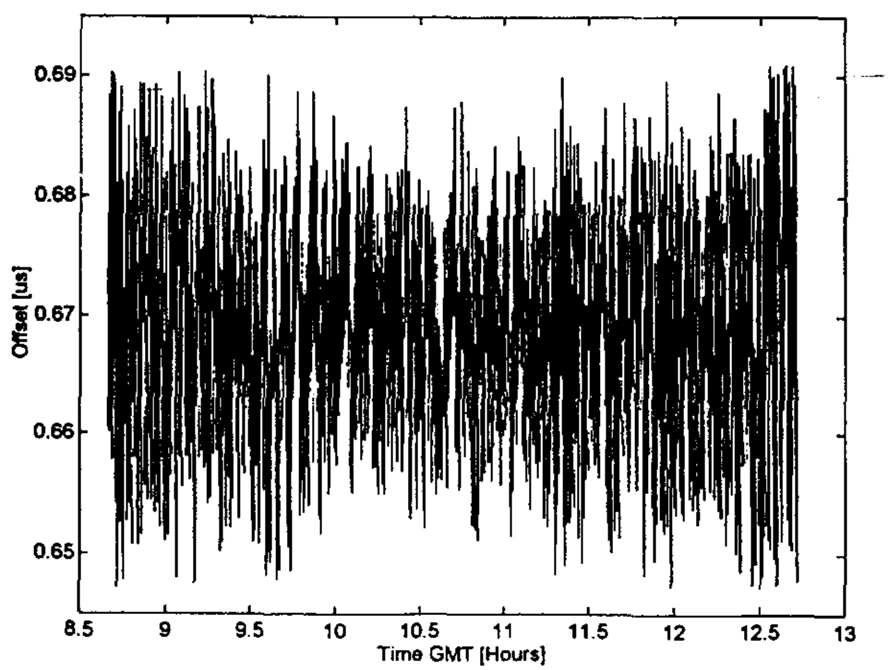

Figure 4: **UTC(LDS) - UTC(NPL2) → GLN 1 on 4 Nov '94**
mean value = 668.8 ns; 1-σ = 7.0 ns

Questions and Answers

WLODZIMIERZ LEWANDOWSKI (BIPM): I have comments concerning GLONASS schedules. There is an experiment schedule in use, a GLONASS schedule, between North America and Europe for the end of June. We are preparing to issue worldwide GLONASS schedules for the beginning of January next year. This schedule is for the observation of slots – not specific GLONASS satellites, but slots – which are moving by, you have to subtract four minutes each day. So we have about the same pattern as for GPS, and have an automated GLONASS schedule, which doesn't have changes often, as is done in Russia. This is to prove it works, now going on for five months. So we hope next January we will have a regular GLONASS schedule.